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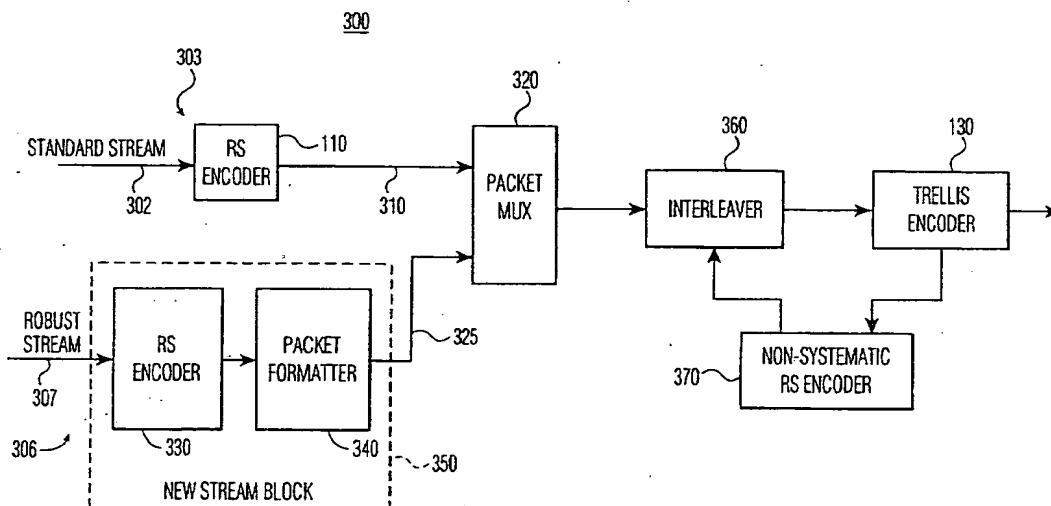
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(54) Title: **DIGITAL TELEVISION SYSTEM**



(57) Abstract: This disclosure describes a flexible digital transmission system that improves upon the ATSC A/53 HDTV signal transmission standard. The system includes a digital television signal transmitter for generating a first Advanced Television Systems Committee (ATSC) standard 8-VSB bit stream and, for generating an encoded new bit stream capable of transmitting high priority information bits, wherein symbols of the new bit stream are capable of being transmitted according to a transmission mode selected from group comprising: a 2-VSB mode, a 4-VSB mode, and a hierarchical-VSB (H-VSB) transmission mode. Each respective 2-VSB, 4-VSB, and H-VSB mode is characterized as having symbols mapped according to possible symbol values from an alphabet comprising respectively,  $\{-7, -5, 5, 7\}$ ,  $\{7, 3, -3, -7\}$ , and  $\{7, 5, 3, -3, -5, -7\}$ . The standard 8-VSB bit stream and new bit stream may be simultaneously transmitted over a terrestrial channel according to a broadcaster defined bit-rate ratio.

Digital television system

The present invention relates to digital transmission systems and particularly, to the Advanced Television Systems Committee (ATSC) Digital Television (DTV) standard (A/53). The invention describes a method for transmitting a robust bit-stream along with the standard bit-stream using the ATSC standard in a backward compatible manner.

5           The ATSC standard for high-definition television (HDTV) transmission over terrestrial broadcast channels uses a signal that comprises a sequence of twelve (12) independent time-multiplexed trellis-coded data streams modulated as an eight (8) level vestigial sideband (VSB) symbol stream with a rate of 10.76 MHz. This signal is converted to a six (6) MHz frequency band that corresponds to a standard VHF or UHF terrestrial  
10 television channel, over which the signal is broadcast at a data rate of 19.39 million bits per-second (Mbps). Details regarding the (ATSC) Digital Television Standard and the latest revision A/53 is available at <http://www.atsc.org/>.

Fig. 1 is a block diagram generally illustrating an exemplary prior art high definition television (HDTV) transmitter 100. MPEG compatible data packets are encoded  
15 for forward error correction (FEC) by a Reed Solomon (RS) encoder unit 110. The data packets in successive segments of each data field are then interleaved by data interleaver 120, and the interleaved data packets are then further interleaved and encoded by trellis encoder unit 130. Trellis encoder unit 120 produces a stream of data symbols having three (3) bits each. One of the three bits is pre-coded and the other two bits are produced by a four (4) state  
20 trellis encoder. The three (3) bits are then mapped to an 8-level symbol as shown in unit 134 (Fig. 3).

As known, trellis encoder unit 130 comprises twelve (12) parallel trellis encoder and pre-coder units to provide twelve interleaved coded data sequences. In  
multiplexer 140 the symbols of each trellis encoder unit are combined with "segment sync"  
25 and "field sync" synchronization bit sequences from synchronization unit 150. A pilot signal is then inserted by pilot insertion unit 160. The symbol stream is then subjected to vestigial sideband (VSB) suppressed carrier modulation by VSB modulator 170. The symbol stream is then finally up-converted to a radio frequency by radio frequency (RF) converter 180.

While the existing ATSC 8-VSB A/53 digital television standard is sufficiently capable of transmitting signals that overcome numerous channel impairments such as ghosts, noise bursts, signal fades and interferences in a terrestrial setting, there exists a need for flexibility in the ATSC standard so that streams of varying priority and data rates may be accommodated.

It would thus be highly desirable to provide a flexible ATSC digital transmission system and methodology that permits a trade-off of the standard bit-stream's data rate for the new bit-stream's robustness.

It would further be highly desirable to provide in an ATSC digital transmission system, an improved technique for transmitting a new bit-stream along with the standard ATSC bit-stream wherein the new bit-stream has a lower Threshold of Visibility (TOV) compared to the ATSC stream, and consequently can be used for transmitting high priority information bits (robust bit-stream).

It would further be highly desirable to provide a terrestrial broadcast system that supports a flexible payload data-rate in a 6-Mhz channel with a flexible Carrier-Noise Ratio (CNR).

It would be further highly desirable to incorporate within the existing ATSC digital transmission standard an improved technique for transmitting a new bit-stream along with the standard ATSC bit-stream wherein the new bit-stream includes high priority information bits, and such that the transmission is backward compatible with existing digital television receiver devices.

Accordingly, it is an object of the present invention to provide a flexible ATSC digital transmission system and methodology that permits a trade-off of the standard bit-stream's data rate for the new bit-stream's robustness.

It is a further object of the present invention to provide in an ATSC digital transmission system, an improved technique for transmitting a new robust bit-stream along with the standard ATSC bit-stream wherein the new bit-stream has a lower Threshold of Visibility (TOV) compared to the ATSC stream, and consequently can be used for transmitting high priority information bits (robust bit-stream). That is, the robust bit-stream may be decodable at a lower TOV and in severe multi-path channel, thus enabling more receivers to receive the signal (effectively increasing the coverage area).

It is another object of the present invention to provide a terrestrial broadcast system that supports a flexible payload data-rate in a 6-Mhz channel with a flexible CNR.

It is yet another object of the present invention to incorporate within the existing ATSC digital transmission standard an improved technique for transmitting a new bit-stream along with the standard ATSC bit-stream wherein the new bit-stream includes high priority information bits, and such that the transmission is backward compatible with existing digital television receiver devices.

It is still another object of the present invention to provide an ATSC digital transmission system and methodology that permits a trade-off of the standard bit-stream's data rate for the new bit-stream's robustness wherein symbols belonging to the standard stream and the new stream are multiplexed and transmitted over a terrestrial channel by the transmitter according to a broadcaster defined bit-rate ratio.

In accordance with the preferred embodiments of the invention, there is provided a digital signal transmission system and methodology comprising: a means for generating a first bit stream, e.g. an ATSC standard 8-VSB bit stream; a means for generating a new bit stream capable of transmitting high priority information bits, said new bit stream and said standard first bit stream capable of being simultaneous transmitted over a fixed bandwidth communications channel to a receiver device capable of receiving said standard and new bit stream, wherein the data rate of the standard bit stream is inversely related to a degree of robustness of information bits comprising the new bit-stream.

In accordance with the preferred embodiments, the two bit-streams are multiplexed at the packet level. The new stream uses robust symbol mapping schemes to transmit one bit of information (robust) per symbol. Three such methods are described including: a pseudo 2-VSB, 4-VSB and hierarchical-VSB (H-VSB). In the pseudo 2-VSB and H-VSB modes, the sign of the symbol indicates the robust information bit. In the 4-VSB mode, the information bit is trellis coded using the existing trellis encoder.

Transmission of a new bit-stream along with the standard ATSC bit-stream using pseudo 2-VSB, 4-VSB, and hierarchical VSB (H-VSB) symbol mapping techniques requires the mapping of symbols, respectively, from the alphabet  $(7, 5, -5, -7)$ ,  $(7, 3, -3, -7)$ , and  $(7, 5, 3, -3, -5, -7)$ .

To insure backward compatibility with existing receivers from various manufacturers, an optional "non-systematic" Reed-Solomon encoder may be used to add parity bytes to the robust bit-stream packets. The standard 8-VSB bit-stream will be encoded using the ATSC FEC scheme  $(A/53)$ . Packets transmitted using the new bit-stream will be ignored by the transport layer decoder of the existing receiver. Thus, the effective payload

that can be decodable by existing receivers is reduced due to the insertion of the new bit-stream.

5                   Details of the invention disclosed herein shall be described below, with the aid of the figures listed below, in which:

                  Fig. 1 illustrates a block diagram of an exemplary high definition television (HDTV) transmitter;

                  Fig. 2 is a simplified top-level diagram of the improved digital broadcast  
10   system 300 for pseudo 2-VSB and 4-VSB according to the present invention;

                  Fig. 3 is a block diagram of one exemplary prior art trellis encoder and pre-coder unit (one of twelve such units shown in Fig. 2) and an eight (8) level symbol mapper; and,

                  Fig. 4 illustrates a simplified diagram of the H-VSB system mode for HDTV  
15   400 in accordance with the principles of the present invention.

                  Fig. 5 is a simplified block diagram of the modified trellis encoder and modified mapping scheme for the hierarchical mode according to the invention.

20                   Known is a system that enables the transmission of a more robust ATSC 8-VSB stream, i.e., a hierarchical VSB or H-VSB, by a digital transmitter. According to this reference, a new ATSC 8-VSB bit stream ("New Stream") is provided in which each bit in a first portion of the bits (e.g., half of the bits) is robust (the "Robust Stream"). The error correcting capacity of bits in the Robust Stream is greater than the error correcting capacity  
25   of bits in a standard ATSC 8-VSB bit stream. The present invention herein described in accordance with Fig. 2 improves upon the known digital transmission system by enabling flexible transmission rates for Robust and Standard streams for accommodating a large range of carrier-to-noise ratios and channel conditions.

                  A representative functional diagram of the improved digital transmission  
30   system 300 for pseudo 2-VSB and 4-VSB according to the invention is now described with respect to Fig. 2. As shown in Fig. 2, the system 300 includes two packet stream paths: a first path 303 corresponding to receipt and processing of the existing ATSC standard bitstream 302 and a second path 306 corresponding to the new (robust) bitstream 307. Preferably, the

standard data and robust stream inputs 302, 307 to the system comprise MPEG compatible packets.

All packets sent via the first path (i.e., the standard or 8-VSB stream 302) are sent using the existing 8-VSB coding scheme. Thus, as shown in Fig. 2, a regular ATSC 8-VSB bit stream (Standard Stream) is input to the Reed Solomon (RS) encoder unit 110. The output 310 of the RS Encoder 110 is input to a packet multiplexer (MUX) 320, which, as will be described, multiplexes both standard stream and robust packets from the respective first and second paths.

As will be described, all packets sent via the robust path 306 are sent using the pseudo 2-VSB or 4-VSB coding scheme in a backward compatible manner. Particularly, the second path 306 includes a new stream processing block 350 including Reed-Solomon encoder device 330 and a packet formatter 340 for processing the input robust stream as will be described in greater detail herein.

Generally, the Standard Stream from Reed Solomon (RS) encoder 110 and the New Stream 325 from the new stream processing block 350 are multiplexed on a packet basis in multiplexer (MUX) 320. The multiplexed Standard Stream and New Stream pass through convolutional data interleaver 360 and then trellis encoded in trellis encoder unit 130. Data interleaver 360 rearranges the bytes of the multiplexed Standard Stream and New Stream during the interleaving process. Trellis encoder 130 encodes bytes belonging to the multiplexed Standard Stream 310 and New Stream 325 and maps the symbols generated by the Standard Stream bytes and by the New Stream bytes in a trellis encode symbol mapper unit as will be described. Additionally, as shown in Fig. 2, there is provided a "non-systematic" Reed Solomon (RS) encoder unit 370 which is a device that is used to satisfy backward compatibility requirements in existing ATSC DTV receivers. An advantageous embodiment of Reed Solomon (RS) encoder 330 is set forth and described in United States Patent Application No. 09/781,486 entitled "System and Method for Sending Low Rate Data on a Packet Basis in an 8-VSB Standard Data Packet Stream" filed on February 12, 2001. The disclosures of United States Patent Application No. 09/781,486 are hereby incorporated by reference in the present patent application as if fully set forth herein. Generally, according to the invention, the "non-systematic" RS encoder 370 ensures that the existing receivers will identify the robust stream packets as valid RS code-words, particularly, by enabling a packet identifier (PID) corresponding to the robust stream packets (for existing receivers) to comprise a Null packet header.

The symbol mapping schemes according to the invention are now described.

Typical VSB receiver devices such as shown in Fig. 2 typically make use of the trellis decoder to aid channel equalization. Thus, it is imperative that the trellis decoder continues to function and decode symbols corresponding to the new stream with reasonable accuracy, so that the performance of the existing receiver won't deteriorate when the new robust stream is transmitted. The proposal uses the existing trellis encoding scheme without any change in the way bytes are read from the data interleaver 360 into the trellis encoder. There is also no change in encoding the packets corresponding to the standard stream.

A detailed functional diagram of an exemplary prior art trellis encoder 130 is shown in Fig. 3. As shown in Fig. 3, the trellis encoder 133 and pre-coder unit 132 provide their outputs to an eight (8) level symbol mapper 134. A multiplexer for coupling the trellis encoder 133 and pre-coder unit 132 to eight (8) level symbol mapper 134 is not shown in Fig. 3. According to the transmission scheme of the invention, each data symbol to be encoded comprises two bits,  $X_1$  and  $X_2$ . Bit  $X_2$  is pre-coded by pre-coder 132 which comprises a one bit register 136 to derive pre-coded bit  $Y_2$ . The Bit  $Y_2$  is not altered further by trellis encoder 130 and is output as bit  $Z_2$ . The other input bit,  $X_1$ , does not pass through pre-coder 132 but does pass through trellis encoder 133 as bit  $Y_1$ . Trellis encoder 133 encodes bit  $X_1$  in accordance with a rate-1/2 convolutional code utilizing one bit data registers, 138, 139. The result is output as bit  $Z_0$  and bit  $Z_1$ . Therefore, three bits (i.e., bit  $Z_0$ , bit  $Z_1$ , and bit  $Z_2$ ) are output by trellis encoder 130 to eight (8) level symbol mapper 134. The eight (8) level symbol mapper 134 converts the three bits  $Z_0$ ,  $Z_1$  and  $Z_2$  to a value "R" in an eight (8) level constellation of permissible code values. The permissible code values for R are -7, -5, -3, -1, +1, +3, +5, and +7. These values correspond with the three bit combinations shown in eight (8) level symbol mapper 134.

According to the invention, for the robust stream 325, the trellis encoder 130 receives a byte, of which only 4-bits (LSBs) contain valid information. When a byte that belongs to the robust stream is received by the trellis encoder 130, the information bits (i.e., LSBs bits (6,4,2,0)) are placed on  $X_1$ , and  $X_2$  is subsequently determined to obtain the particular symbol mapping scheme. Once  $X_2$  is determined, the 4-MSBs of the byte, e.g., bits (7,5,3,1), will be replaced by these values. When all the bits of a byte are determined, a new byte will then have been formed containing the LSBs and the MSBs. This byte is then passed to the "non-systematic" Reed-Solomon encoder 370 of Fig. 2. As will be described in greater detail, the parity bytes of the "non-systematic" Reed-Solomon encoder 370 and the PID bytes

(not shown) will however be encoded using the 8-VSB encoding scheme. The symbol mapping techniques for each mode are now described as follows:

- pseudo 2-VSB Mode

In view of Fig. 3, the 2-VSB mode is obtained by making Z2 and Z1 equal to the information bit X1 (i.e., LSB bits (6,4,2,0)). The X2 is then calculated such that, when pre-coded, it results in Z2. This operation is nothing other than  $X2 = X1 + Y2d \text{ mod } 2$ , where Y2d is the content of the register 136 of the pre-coder 132. This operation, combined with the existing symbol mapping scheme, results in symbols from the alphabet  $\{-7, -5, 5, 7\}$ . This is essentially a pseudo 2-VSB signal in the sense that the information bit is transmitted as the sign of this symbol. The actual symbol is a valid trellis coded 4-level symbol which can be decoded by existing trellis decoder devices.

- 4-VSB Mode

In view of Fig. 3, the 4-VSB mode is obtained by making Z1 equal to the information bit. X2 is then calculated such that when pre-coded, Z2 equals Z0. This operation is nothing other than  $X2 = Z0 + Y2d \text{ mod } 2$ , where Y2d is the content of the pre-coder register 136. These operation and the use of the existing symbol mapping results in symbols from the alphabet  $\{-7, -3, 3, 7\}$  which is essentially a trellis coded 4-VSB symbol. The actual 4-level symbol is a valid trellis coded symbol that can be decoded by existing trellis decoders.

Referring back to Fig. 2, the new stream processor block 350 is primarily composed of a Reed-Solomon encoder 330 and a packet formatter 340. The Reed-Solomon encoder 330 adds parity bytes to the robust packets in the same manner as the Reed-Solomon encoder 110 of the standard stream. The incoming 187-byte packet (e.g., of an incoming MPEG-II packet) is appended with 20 parity bytes to result in 207 bytes. These bytes will then be post processed and sent using robust constellations. The packet formatter 340 essentially buffers and groups the incoming bit-stream into groups of 207 bytes. In general, only 4 bits of each byte at the packet formatter output, the LSBs (6,4,2,0), correspond to the incoming stream. The other 4 bits of each byte, the MSBs (7,5,3,1), may be set to any value.

Referring back to Fig. 2, if the "non-systematic" Reed-Solomon encoder is used, then only 187 bytes will be created in this way to carry  $4 \times 187$  bits of the robust stream. The remaining 20 bytes will be determined after these 187 bytes are trellis coded in a special way to obtain (pseudo) 2-VSB and 4-VSB symbols. In creating the 207 bytes, the 187 bytes containing the information stream and the other 20 bytes, the specific values of which are at this processing stage yet to be determined, will be permuted in such a way that after the data interleaver, these 20 bytes will appear at the end of the 187 bytes. At this new stream



processing stage, the values of the 20 bytes can be set to any value. If, however, the "non-systematic" Reed-Solomon encoder is not used, then all the LSBs of the 207 bytes will correspond to  $207 \times 4$  bits from the incoming robust bit-stream. In this case, the 187-byte MPEG compliant packet will be transmitted using  $828 \times 2$  symbols.

5 In addition to the above, the packet formatter 340 may additionally add an optional PID, e.g., 3-bytes, such that the existing receivers will process packets containing the robust stream as null packets. This PID will typically be set to "null packet". When the PID bytes are inserted, the information bits of the robust stream will be included in 184 bytes only. This mode implies the use of the "non-systematic" Reed-Solomon encoder. This mode, 10 incorporated for the purpose of improving backward compatibility, will reduce the effective data rate as 23 bytes (20 parity bytes and 3 PID bytes) have to be added per packet by the packet formatter.

Referring again to Fig. 2, the present invention provides various options as to how the new packets will be processed by existing receivers. The first option is one for which 15 the new packets will not be correctly decoded by the Reed-Solomon decoders of existing receivers. The second option is one for which the new packets will be decoded correctly by the Reed-Solomon decoders of existing receivers. However, the existing receivers will not be able to decode the information from these packets. This option is proposed to provide the flexibility to cover the widest possible set of the existing receivers from different 20 manufacturers. The use of the additional ("non-systematic") Reed-Solomon encoder to insure backward compatibility, however, reduces the total payload by an amount equal to the parity bytes. When all of the existing receivers are phased out, broadcasters may choose not to use this option, to increase the effective payload of the robust stream.

The Reed-Solomon encoder defined in the existing ATSC A/53 standard 25 appends parity bytes at the end of the 187-byte packet to yield a 207-byte codeword. This encoding scheme is known as a systematic code. However, Reed-Solomon codes need not be systematic. Given a particular application, the encoding may be performed in such a way that the parity bytes are placed in arbitrary positions in the total 207 available byte positions. The resulting codeword is a valid Reed-Solomon codeword from the systematic code family. A 30 Reed-Solomon decoder does not need knowledge of the parity byte positions. Thus, an unmodified Reed-Solomon decoder that decodes the systematic code will additionally decode this code.

In the encoding process, the "non-systematic" Reed-Solomon encoder collects all the 187 bytes corresponding to the robust stream. The trellis encoder produces these bytes

as described herein. Given the positions of the parity bytes, the Reed-Solomon encoder then produces 20 parity bytes corresponding to this packet. The parity bytes will then be appropriately placed in the data interleaver at the positions corresponding to the last 20 bytes of the 207 byte packet.

5           The hierarchical VSB (H-VSB) mode transmits 2-bits of information per symbol with different degrees of priority. In a similar manner to the DVB-T hierarchical mode, the sign of the symbols corresponds to the high-priority bit while the level within a symbol corresponds to the low-priority bit.

10           In this H-VSB mode, the overall payload of the system is not significantly reduced, unlike for the pseudo 2-VSB and 4-VSB modes. The broadcaster will be able to transmit three bit-streams: one stream being the regular ATSC bit-stream (Standard Stream, SS) and the other two new bit-streams being (New Stream, NS, comprised of a "robust" stream (high priority bit-stream)) and an "embedded" stream (low priority bit-stream). A new receiver would be able to decode all the bit-streams while an existing receiver will be able to  
15   decode SS packets and dump NS packets. The broadcaster has the ability to transmit different services at different levels of robustness.

          Fig. 4 illustrates a simplified diagram of the H-VSB system mode of transmission 400. As shown in Fig. 4, the two bit-streams SS 302 and NS 308, 309 are multiplexed on packet basis by the packet mux 320 at the input to the FEC block (not  
20   shown). The multiplexed bit-streams are then passed through the convolutional interleaver 360 before being encoded by a trellis encoder 380. The hierarchical block 350' processes the two streams belonging to the high priority stream 308 and the embedded low priority stream 309. Respective Reed-Solomon encoder devices 330, 331 each encodes packets corresponding to a respective stream 308, 309. The packet formatter 340 then combines these  
25   streams such that the MSBs of a byte, (i.e., bits 7,5,3,1), correspond to the high-priority stream and the LSBs, bits (6,4,2,0), of a byte correspond to the embedded stream. In general, after Reed-Solomon encoding, two 207-byte composite packets are formed from two 187-byte MPEG compliant input packets.

          In this mode, the trellis encoder 380 encodes bytes belonging to the two bit-  
30   streams and maps the symbols generated by standard stream bytes and new stream bytes using the mapping table illustrated in Fig. 5 with  $\alpha = 0$  and  $\alpha = 2$ , respectively. As the bit X2 may be derived from the sign information of the received symbol, increasing the distance between +1 and -1 levels improves the reliability of this bit at the decoder. Using this new system, high priority bits of the new stream may be sent to X2 input and low priority bits of

NS may be sent to  $X_1$  input of the trellis encoder. In a similar manner as for pseudo 2-VSB,  $X_2$  may additionally be computed such that the output of the pre-coder,  $Z_2$ , equals the high priority bit. Subsequently, the "non-systematic" Reed-Solomon encoder 370 may then be used to add 20 parity bytes. These operations ensure that, given adequate SNR, the new packets will not be flushed as error by the Reed-Solomon decoders of existing receivers.

Fig. 5 is a simplified block diagram of the modified trellis encoder 380 and modified mapping scheme for the hierarchical mode according to the invention; a control block (not shown) is provided to generate the appropriate control signals necessary for setting the value of  $\alpha = 0$  in the symbol mapper unit, for example, when Standard Stream bytes are present in trellis encoder 380; and, setting the value of  $\alpha = 2$  when New Stream bytes are present in the symbol mapper unit 134'. As shown in Fig. 5, if the value of  $\alpha$  is set equal to one (1) then the  $R$  value for the bit combination zero one one (011) is minus two (-2) and the  $R$  value for the bit combination one zero zero (100) is plus two (+2). Because the  $X_2$  bit can be derived from the sign information of the received symbol, increasing the distance between the -1 level and the +1 level improves the reliability of the  $X_2$  bit at the decoder. When the value of  $\alpha$  is set equal to zero (0) the distance between the -1 level and the +1 level is two (2) units. When the value of  $\alpha$  is set equal to two (2) the distance between the -3 level and the +3 level is equal to six (6) units. In this alternate advantageous embodiment of the present invention, the  $Z_2 Z_1 Z_0$  bits "010" and the  $Z_2 Z_1 Z_0$  bits "011" both give the same  $R$  value of minus three (-3). This is not a problem because for the Robust Stream only the sign of the received symbol is needed. So for both "010" and "011" the sign is negative and the decoded bit  $X_2$  is zero (0). Similarly, the  $Z_2 Z_1 Z_0$  bits "100" and the  $Z_2 Z_1 Z_0$  bits "101" both give the same  $R$  value of plus three (+3). For both "100" and "101" the sign is positive and the decoded bit  $X_1$  is one (1). Using the apparatus and method of the present invention, the high priority bits in a New Stream (i.e., the Robust Stream) can be sent to the  $X_2$  input of trellis encoder 630 and the low priority bits in a New Stream (i.e., the Embedded Stream) may be sent to the  $X_1$  input of trellis encoder 380. Packet multiplexer 320 ensures that the  $X_2$  input of trellis encoder 380 receives the Robust Stream bits and that the  $X_1$  input of trellis encoder 380 receives the Embedded Stream bits.

In an alternative embodiment, the control information for setting the values of the  $\alpha$  in the symbol mapper unit 134' for pseudo 2-VSB, 4-VSB and H-VSB modes, is communicated at the packet level.

An intended receiver, depending on its state (location, mobility, etc.) may decode the high priority information (robust stream) and if the SNR is sufficient may

additionally decode the low priority information (standard and embedded streams). In an existing receiver, the new stream will cause some errors during the trellis decoding process. As a result of this, the receiver will use some of its error correcting capability to correct these errors. This will cause the TOV to increase by a small amount. Once all the packets are  
5 corrected by the FEC, the transport layer (or the MPEG decoder) will discard the packets belonging to the new stream NS and will only use packets belonging to the standard stream for source decoding.

According to the invention, the transmitter specifies, on a data field basis (313 segments), the placement of the new robust packets within a field. To simplify receiver  
10 implementation, the first symbol of a specified segment in a field may correspond to the first symbol of the robust packet. The number and mode of the robust packets are specified in the reserved bits of the field sync segment. All the information needed to decode the robust packets are specified in the reserved bits. This information includes: 1) the Mode (i.e., pseudo 2-VSB, 4-VSB, H-VSB); 2) whether the optional "non-systematic" RS encoder is used; and,  
15 3) the number of robust packets that start in the following field.

The improved digital transmission system of the invention incorporates a built-in flexibility enabling adaptation to different types of channels, while at the same time providing flexibility in the overall payload distribution. It is capable of operating at low CNR in different channel impairment environment viz. Gaussian, Ricean and Rayleigh. The system  
20 may withstand strong (up to 0 dB), long delay static multi-path interference and also dynamic multi-path interference.

The system further features a number of selectable parameters that accommodate a large range of carrier-to-noise ratios and channel conditions. It allows fixed, portable and/or mobile reception by trading off the data rates for robustness. This wide range  
25 of parameters allows the broadcasters to select a mode appropriate for current applications or for some anticipated future applications. For instance, a moderately robust mode (with a correspondingly lower data rate) is needed to ensure reliable portable reception with a simple set-top antenna. A less robust mode with a higher data rate can be used where the service can be received at relatively higher TOV. The less robust modes with larger payloads may be  
30 used for fixed reception while the robust modes with the smaller payloads may be used for mobile and portable reception.

Table 1 presents representative payload (Mb/s) and performance parameters for different bit-rate ratios of the new stream to the standard 8-VSB stream. An intended representative receiver is assumed for all the performance parameters.

Table 1:

Mix ratio (New/8-VSB)	Robust stream	Standard stream	Total	Robust stream	Embedded stream	Standard stream	Total
100/0	8.7-9.6	-	8.7-9.6	8.7-9.6	8.7-9.6	-	17.4-19.3
50/50	4.3-4.8	9.6	13.9-14.4	4.3-4.8	4.3-4.8	9.6	18.2-19.3
20/80	1.7-1.9	15.4	17.1-17.3	1.7-1.9	1.7-1.9	15.4	18.8-19.3
10/90	0.9-1.0	17.3	18.2-18.3	0.9-1.0	0.9-1.0	17.3	19.1-19.3
0/100	-	19.3	19.3	-	-	19.3	19.3

- 5 Table 2 illustrates the TOV (in dB) of pseudo 2-VSB, 4-VSB, H-VSB and 8-VSB for AWGN channel for an intended (new) receiver for a bit-error rate of  $2 \cdot 10^{-3}$  at the Reed-Solomon decoder input.

Table 2:

Mix ratio	2-VSB	4-VSB	8-VSB	16-VSB	32-VSB	64-VSB	128-VSB
100/0	8.5	9.8	-	-	-	-	-
50/50	8.5	12.0	12.5	19.1	16.3	15.6	15.5
20/80	8.6	14.0	12.2	16.4	15.3	14.6	15.4
10/90	8.7	14.5	12.0	16.2	15.0	14.6	15.1
0/100	-	-	-	-	14.9	14.9	14.9

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Advantageously, new receivers will be able to decode robust packets without errors even under severe static and dynamic multi-path interference environments at reduced CNR. As can be seen, the TOV (in additive white noise) is also reduced to as little as 8.5 dB.

- 5 This significant improvement in performance is achieved with little performance penalty to packets encoded using the existing 8-VSB standard. Moreover, the system does not require a change in the power mask. The average power required to transmit bit-streams in different modes is almost equal to the existing levels.

- 10 Table 3 illustrates the TOV(in dB) of pseudo 2-VSB, 4-VSB, H-VSB and 8-VSB for Ricean channel using a representative receiver. This is obtained for a bit-error rate of  $2 \cdot 10^{-3}$  at the Reed-Solomon decoder input. The channel used is  $(1 \ 0 \ 0 \ 0 \ 0.7)/\sqrt{1.5}$ .

Table 3:

Mix- ratio	2-VSB	4-VSB	H-VSB	8-VSB	8-VSB	8-VSB	8-VSB
100/0	11.4	15.2	17.0	-	-	-	-
50/50	10.5	14.6	16.7	20.3	20.5	20.1	-
20/80	12.3	18.5	17.0	-	19.0	18.7	-
10/90	-	-	-	-	-	-	-
0/100	-	-	-	-	19.1	19.1	19.1

15

Table 4 illustrates the TOV(in dB) of pseudo 2-VSB, 4-VSB, H-VSB and 8-VSB for Rayleigh channel using a representative receiver. This is obtained for a bit-error rate of  $2 \cdot 10^{-3}$  at the Reed-Solomon decoder input. The channel used is  $(1 \ 0 \ 0 \ 0 \ 1)/\sqrt{2}$ .

Table 4:

Mix ratio	100/0	50/50	20/80	10/90	0/100	100/0	50/50	20/80	10/90	0/100
100/0	13.0	20.2	-	-	-	-	-	-	-	-
50/50	-	-	-	-	-	-	-	-	-	-
20/80	12.0	>22	-	-	-	-	-	-	-	-
10/90	-	-	-	-	-	-	-	-	-	-
0/100	-	-	-	-	23	23	23	23	23	23

Exemplary pseudo 2-VSB and 4-VSB system modes of operation are now described. As depicted in Tables 1-4, two different bit-streams (standard bit-stream and robust bit-stream) may be transmitted using the same physical channel. As an example, according to Table 2, in pseudo 2-VSB mode, for a 20/80 (approx.) mix, robust bit-stream has a TOV at 8.6 dB while the standard bit-stream has a TOV at 15.3 dB (in AWGN environment). In 4-VSB mode, for 20/80 (approx.) mix, the robust bit-stream has a TOV at 14.0 dB while the standard bit-stream has a TOV at 14.6 dB (in AWGN environment). The performance of the standard bit-stream is affected due to the effective power reduction of the 8-VSB symbols in pseudo 2-VSB mode, while 4-VSB mode doesn't affect the standard bit-stream's performance significantly. It should be understood that any value of bit-rate ratio may be used, however, increasing the percentage of robust bit-stream will reduce the data rate of standard bit-stream. If the "non-systematic" RS encoder is used as in Fig. 2, then the system is backward compatible up to the transport layer, but the useable data rate of the robust stream is reduced. If the "non-systematic" RS encoder is not used, then the RS decoder in the existing receiver will set the error flag for the new packets. According to the 2/4-VSB systems, modifications to the ATSC FEC block include the provision of one pre-processor including an RS encoder and a packet formatter. Use of a "non-systematic" RS encoder within the FEC block is optional.

The proposal also provides a flexible scheme that allows a trade-off to be made between the payload data rates sent using the two streams. For example, using pseudo

2-VSB mode, a 2 Mbps robust bit-stream can be transmitted together with a 15.3 Mb/s standard bit-stream. In this mode, the (Additive White Gaussian Noise) AWGN CNR (TOV) for the robust bit-stream and the standard bit-stream will be 8.5 dB and 15.1 dB respectively.

Exemplary H-VSB system mode of operation is now described. As depicted in  
5 Tables 1-4, two different bit-streams (standard bit-stream and robust bit-stream) may be transmitted using the same physical channel. However, the new stream in turn may comprise a robust stream and an embedded low-priority stream. The H-VSB mode of operation implements a hierarchical system in the sense that different bits have varying levels of error correcting capabilities. High priority bits of the new stream are more robust compared to the  
10 standard 8-VSB stream. The broadcaster may choose the mix of standard and new stream packets. The new stream packets may be time-multiplexed with the standard packets allowing attractive high/low priority payload tradeoffs. The total payload of the system is higher than that of 2/4-VSB systems. As in the 2/4-VSB systems, modifications to the ATSC FEC block: include the addition of one pre-processor comprising an RS encoder and a packet  
15 formatter. The "non-systematic" RS encoder within the FEC block is optional. Symbol levels are changed based on control information.

Using H-VSB mode, a 2 Mbps robust bit-stream can be transmitted along with a 15.3 Mb/s standard bit-stream and a 2 Mb/s embedded stream. The TOV in this mode is about 12 dB and 15.4 dB for the robust bit-stream and standard bit-stream respectively.

20 Due to various receiver implementations of different manufacturers, it is rather difficult to predict their behavior for the non standard bit-stream packets. Therefore, a flexible approach is proposed that will enable the broadcasters to adjust the system parameters to get maximum possible coverage. These include the use of an optional Reed-Solomon encoder to insure that new bit-stream packets will not be flagged as error packets by  
25 the Reed-Solomon decoder of existing receivers. The use of this optional encoder reduces the data rate of the robust bit-stream by  $4 \times 20$  bits per packet, but might be useful during the initial transition period.

The 2/4-VSB and H-VSB modes of the invention as described herein, may be supported by changes in a modem part of the system. Little change is assumed on the  
30 transport layer, however, some control will be needed at the transport layer level to make sure that the modem gets the needed packet rate for each stream path. This operation, in principle, is not different from known system operation at the transport layer level.

While there has been shown and described what is considered to be preferred embodiments of the invention, it will, of course, be understood that various modifications and



changes in form or detail could readily be made without departing from the spirit of the invention. It is therefore intended that the invention be not limited to the exact forms described and illustrated, but should be constructed to cover all modifications that may fall within the scope of the appended claims.

## CLAIMS:

1. A digital signal transmission system comprising:
  - a) means (303) for generating a first bit stream, e.g. an Advanced Television Systems Committee (ATSC) standard 8-VSB bit stream;
  - b) means (306, 350) for generating a new bit stream capable of transmitting  
5 high priority information bits, said new bit stream and said first bit stream capable of being simultaneously transmitted over a fixed bandwidth communications channel to a receiver device, wherein a data rate of said standard bit stream is inversely related to a degree of robustness of information bits comprising said new bit-stream.
- 10 2. The digital signal transmission system as claimed in claim 1, wherein symbols of said new bit stream (307) are transmitted according to a mapping scheme (134') selected from: a pseudo 2-VSB symbol mapping scheme and 4-VSB symbol mapping scheme.
3. The digital signal transmission system as claimed in claim 1, wherein symbols  
15 (307) of said new bit stream mapped according to either one of said pseudo 2-VSB symbol mapping technique and 4-VSB symbol mapping technique are transmitted in a backwards compatible manner (370).
4. The digital signal transmission system as claimed in claim 1, wherein the first  
20 bit stream and new bit stream capable of transmitting high priority information bits are transmitted according to a defined bit-rate ratio.
5. The digital signal transmission system as claimed in claim 1, wherein said new  
bit stream has a lower Threshold of Visibility (TOV) than said first stream.
- 25 6. The digital signal transmission system as claimed in claim 3, further comprising:
  - a first Reed-Solomon encoder means (110) capable of receiving a standard stream (302) of bits and encoding said stream according to an ATSC 8-VSB standard;

- a second Reed-Solomon encoder means (330) capable of receiving a stream of high priority information bits and encoding said stream of high priority information bits to generate said new bit stream; and,

- multiplexing means (320) for multiplexing said standard 8-VSB bit stream and new bit stream for transmission.

7. The digital signal transmission system as claimed in claim 6, wherein said second Reed-Solomon encoder means further comprises a packet formatter device (340) for buffering an input of high priority information bit stream and grouping said bit stream into a predetermined number of bytes.

8. The digital signal transmission system as claimed in claim 6, further comprising:

- a data interleaver device (360) capable of rearranging the bytes of the multiplexed standard 8-VSB stream and new stream during an interleaving process; and,

- a trellis encoder device (130, 133) coupled to an output of said data interleaver device for encoding bytes of said standard and said new bit stream; and,

- a symbol mapper device (134) coupled to said trellis encoder for mapping encoded bits into an associated symbol level according to an associated symbol mapping scheme.

9. The digital signal transmission system as claimed in claim 8, wherein only information bits of each said bytes of said new stream (307) are to be encoded by said trellis encoder device.

10. The digital signal transmission system as claimed in claim 9, wherein said information bits of each said bytes of said new stream are least significant bits (LSB) bits corresponding to bits 6, 4, 2, and 0.

11. The digital signal transmission system as claimed in claim 9, wherein said symbol mapper device (134) generates an output R corresponding to a combination of three bits  $Z_0$ ,  $Z_1$  and  $Z_2$ , said pseudo 2-VSB symbol mapping technique including making  $Z_1$  and  $Z_2$  bits equal to the information bit to result in an output R having one of four possible

symbol values from an alphabet comprising  $\{-7, -5, 5, 7\}$ , wherein a sign of said symbol (R) indicates a robust information bit.

12. The digital signal transmission system as claimed in claim 9, wherein said  
5 symbol mapper device (134') generates an output R corresponding to a combination of three bits  $Z_0$ ,  $Z_1$  and  $Z_2$ , said 4-VSB symbol mapping technique including making  $Z_1$  equal to the information bit and  $Z_2$  equal to  $Z_0$  to result in an output R having one of four possible symbol values from an alphabet comprising  $\{-7, -3, 3, 7\}$ .

10 13. The digital signal transmission system as claimed in claim 9, further comprising a "non-systematic" Reed Solomon encoder device (370) coupled to said data interleaver device (360) and said trellis encoder device (380), said "non-systematic" Reed Solomon encoder device capable of providing said apparatus with backward compatibility for an existing ATSC 8-VSB receiver.

15

14. The digital signal transmission system as claimed in claim 13, wherein said packet formatter device (340) further comprises means for adding packet identifier (PID) bytes to said new stream for enabling said system to implement said "non-systematic" Reed Solomon encoder device (370) when processing said new bit stream.

20

15. The digital signal transmission system as claimed in claim 1, wherein symbols of said new bit stream (307) are transmitted according to a hierarchical VSB (H-VSB) symbol mapping technique, said digital transmission system comprising:

25 - a first Reed-Solomon encoder means (110) capable of receiving a standard stream of bits and encoding said stream (302) according to an ATSC 8-VSB standard;

- a hierarchical processing means (350') capable of encoding a second bit stream of high priority information bits, wherein said second bit stream comprises a first portion of bits to be encoded as a robust ATSC bit stream (308) and a second portion of bits to be encoded as a low priority embedded bit stream (309);

30

- a packet multiplexer device (320) having a first input coupled to an output of said first Reed-Solomon encoder means (110) and having a second input coupled to an output of said hierarchical processing means (350'), said multiplexer (320) capable of multiplexing said standard stream (302) and said second bit stream (308, 309).

16. The digital signal transmission system as claimed in claim 15, further comprising:

- a second Reed-Solomon encoder means (330) capable of receiving said first portion of bits to be encoded as a robust ATSC bit stream;

5 - a third Reed-Solomon encoder means (331) capable of receiving said second portion of bits to be encoded as a low priority 8-VSB embedded bit stream; and,

- a packet formatter device (340) for combining said robust ATSC bit stream and said low priority embedded bit stream for input to said second input of said packet multiplexer device (320).

10

17. The digital signal transmission system as claimed in claim 16, wherein said packet formatter device (340) comprises means for generating bytes, each byte having most significant bits (MSBs) at bits (7,5,3,1) corresponding to high priority bits and least significant bits LSBs at bits (6,4,2,0) correspond to the embedded stream.

15

18. The digital signal transmission system as claimed in claim 16, further comprising:

- a data interleaver device (360) capable of rearranging the bytes of the multiplexed standard 8-VSB stream and new stream during an interleaving process; and,

20

- a trellis encoder device (380, 133) coupled to an output of said data interleaver device (360) for encoding bytes of either said standard or said new bit stream; and,

- a symbol mapper device (134') coupled to said trellis encoder (133) for mapping encoded bits into an associated symbol level according to an associated symbol mapping scheme, wherein said symbol mapper device generates an output symbol R corresponding to a combination of three bits  $Z_0$ ,  $Z_1$  and  $Z_2$ , a value of R comprising  $(-1-\alpha)$  assigned to a combination of  $Z_2$ ,  $Z_1$  and  $Z_0$  equal to (011) and, a value of R comprising  $(1+\alpha)$  assigned to a combination of  $Z_2$ ,  $Z_1$  and  $Z_0$  equal to (100), wherein  $\alpha$  has a variable value.

25

30

19. A method for transmitting digital signals comprising the steps of:

a) receiving a standard stream of bits (302) and Reed-Solomon encoding (110) said stream, e.g. according to an ATSC 8-VSB standard;

b) receiving a stream of high priority information bits (307) and Reed-Solomon encoding (330) said stream of high priority information bits to generate a new bit stream; and,

5 c) multiplexing (320) said standard bit stream and new bit stream for simultaneous transmission over a fixed bandwidth communications channel to a receiver device capable of receiving said standard and new bit stream, wherein a data rate of said standard bit stream is inversely related to a degree of robustness of information bits comprising said new bit-stream.

10 20. The method for transmitting digital signals according to claim 19, wherein symbols of said new bit stream (307) are transmitted according to a mapping scheme selected from: a pseudo 2-VSB symbol mapping scheme and 4-VSB symbol mapping scheme.

21. The method for transmitting digital signals according to claim 20, wherein  
15 symbols of said new bit stream are transmitted according to a hierarchical VSB (H-VSB) symbol mapping technique, said method comprising:

- receiving a standard stream of bits (302) and Reed-Solomon encoding said stream according to an ATSC 8-VSB standard;

20 - receiving a second bit stream (308) of high priority information bits, said second bit stream comprising a first portion of bits to be encoded as a robust ATSC bit stream and a second portion of bits to be encoded as a low priority embedded bit stream (309); and,

- multiplexing (320) said standard stream and said second bit stream for said simultaneous transmission.

25

22. A flexible digital transmission system comprising a digital television signal transmitter and digital television receiver, said transmitter comprising:

- means for generating a first bit stream, e.g. an Advanced Television Systems Committee (ATSC) standard 8-VSB bit stream (302);

30 - means for generating an encoded new bit stream capable of transmitting high priority information bits (307), wherein symbols of said new bit stream are capable of being transmitted according to a transmission mode selected from a group comprising: a pseudo 2-VSB mode, a 4-VSB mode, and a hierarchical-VSB (H-VSB) transmission mode, each mode

characterized as having symbols mapped according to a respective symbol mapping scheme (134, 134'); and,

- multiplexer means (320) for multiplexing symbols representing said first bit stream and said new bit stream for simultaneous transmission over a terrestrial channel
- 5 according to a broadcaster defined bit-rate ratio.

23. The flexible digital transmission system comprising a digital television signal transmitter and digital television receiver as claimed in claim 22, wherein a data rate of said first standard bit stream is inversely related to a degree of robustness of information bits

10 comprising said new bit-stream.

1/5

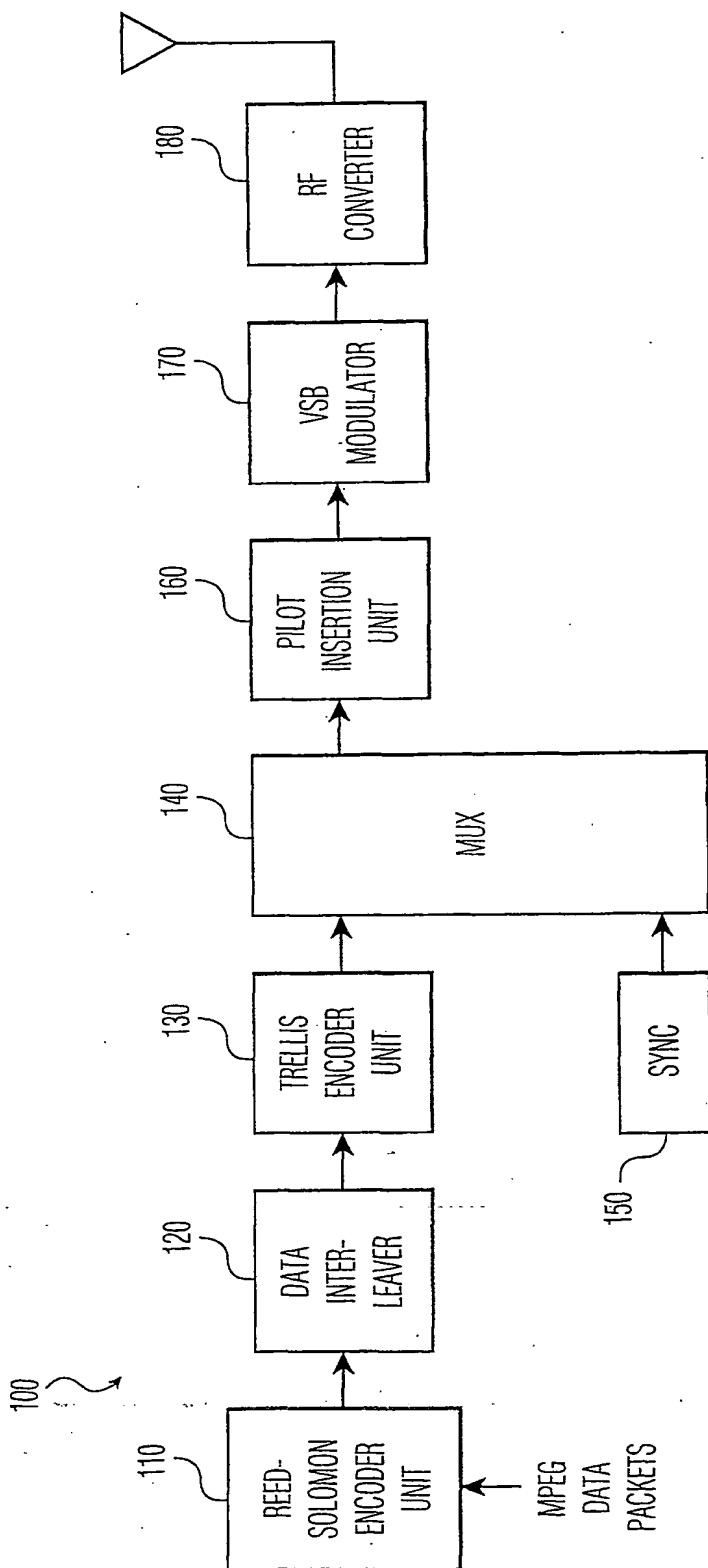


FIG. 1



2/5

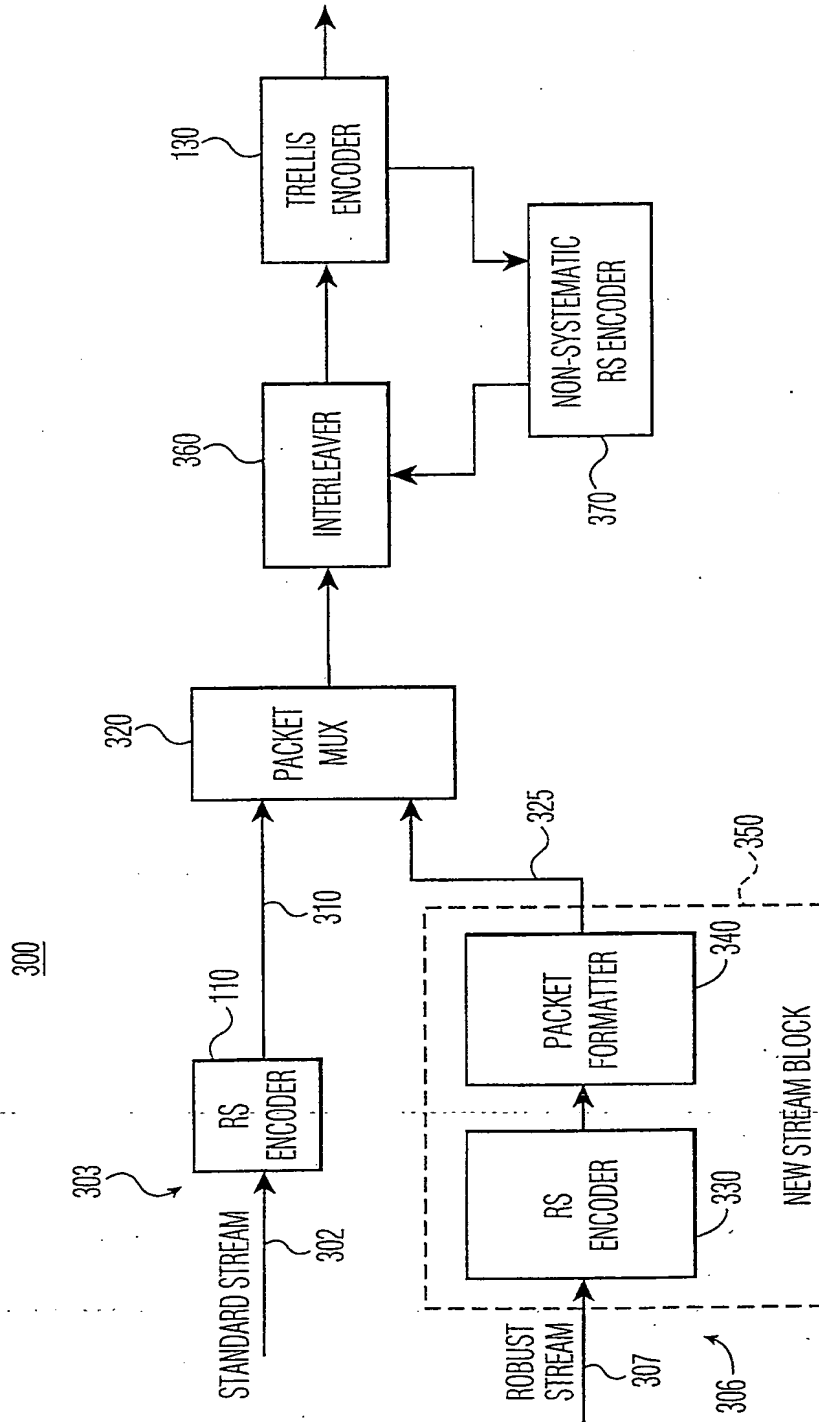
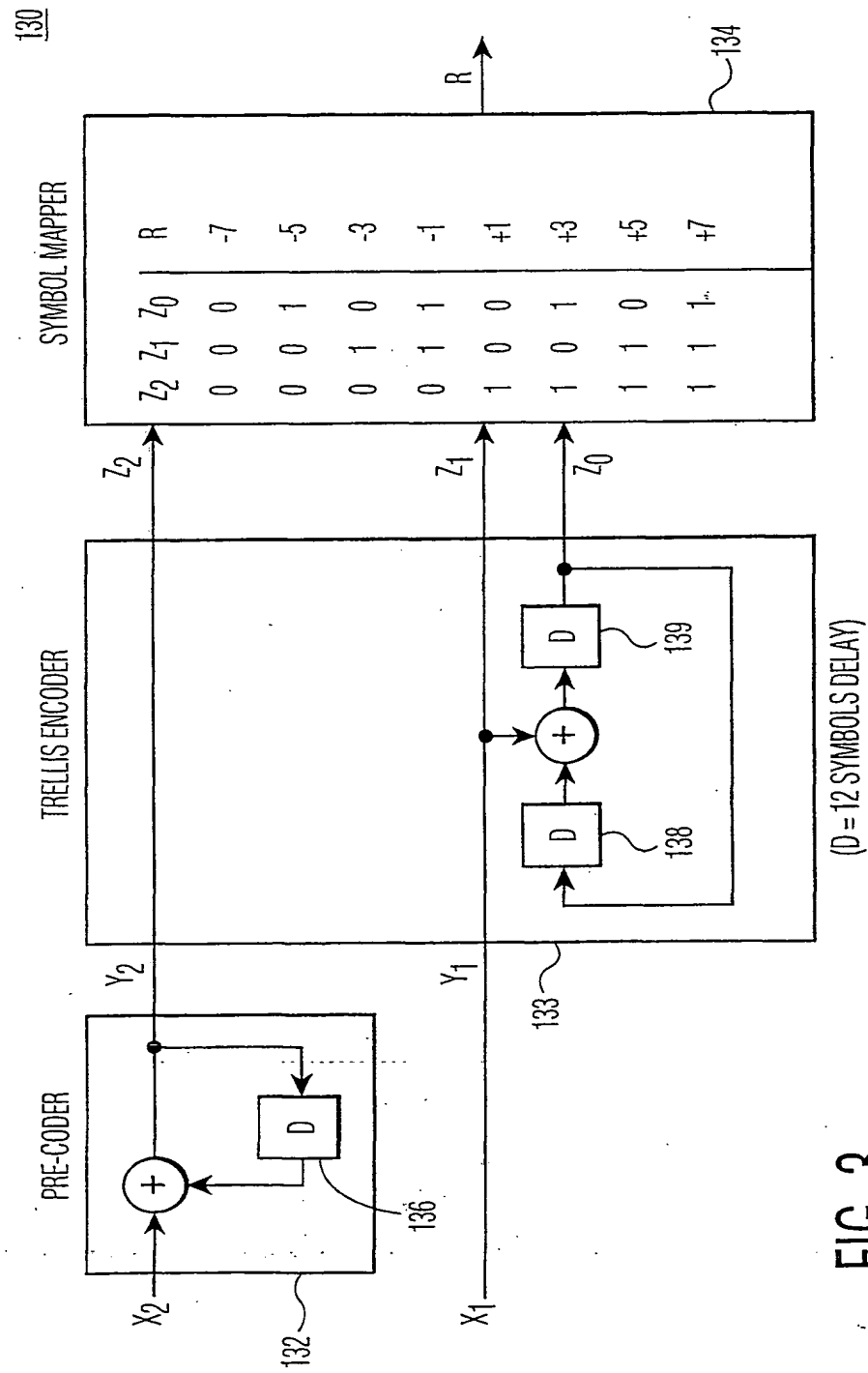


FIG. 2

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4/5

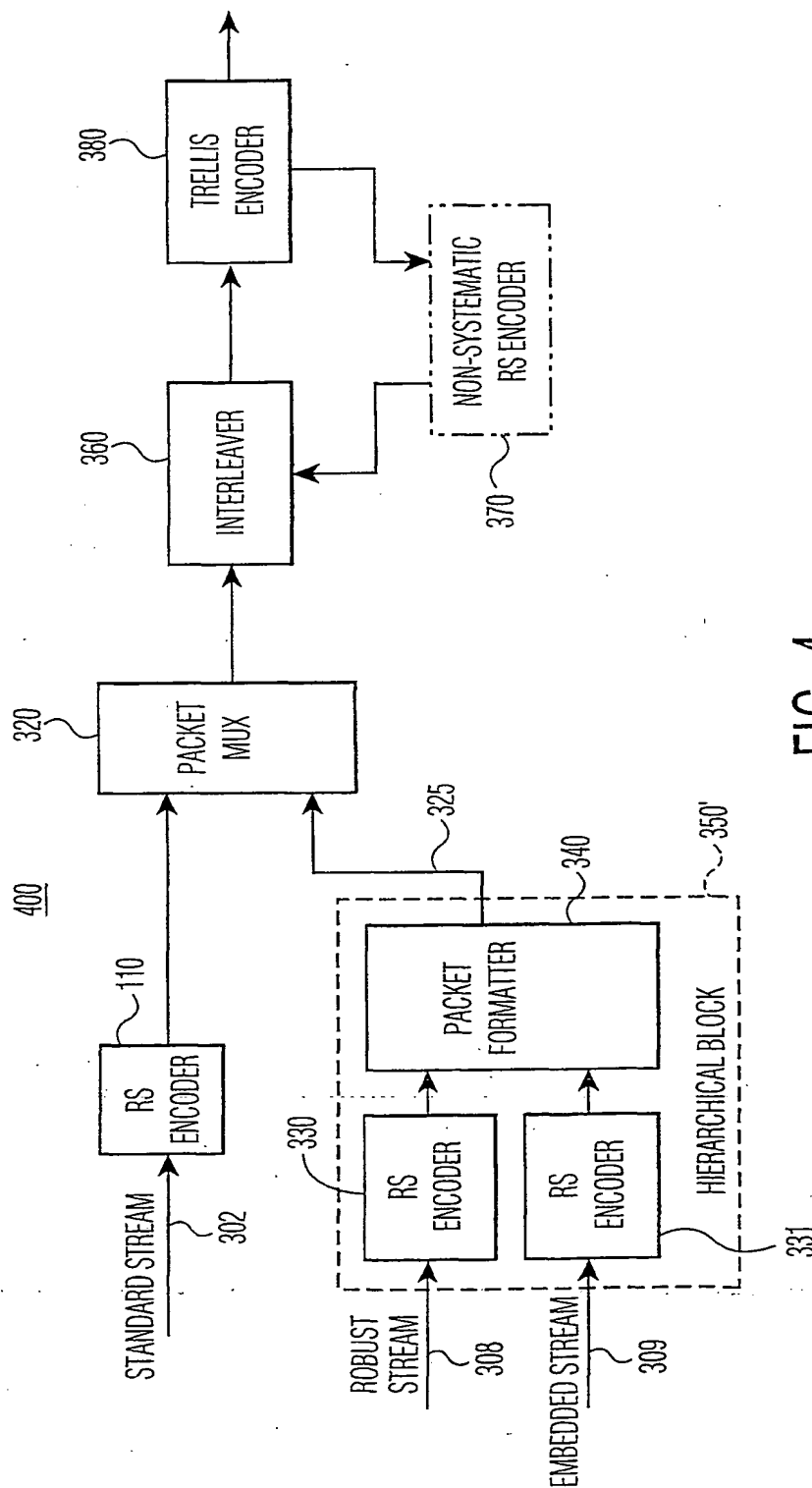


FIG. 4

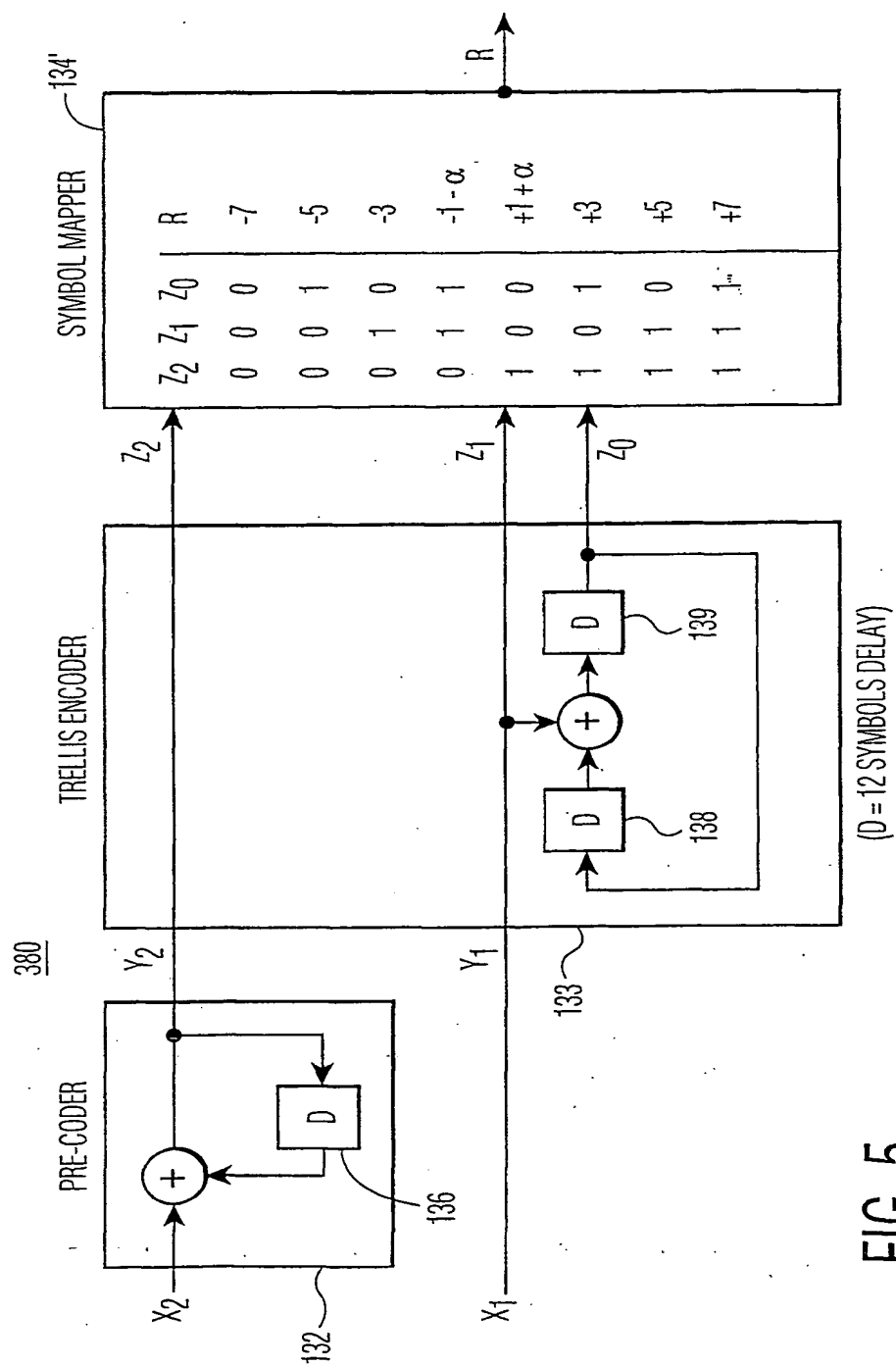


FIG. 5